Federal Register. July 18, 1991: 56(138): 33050–33127.

2. Rand PW, Lacombe EH, Perkins WD Jr. Radon in homes following its reduction in a community water supply. *J Am Water Works Assoc.* 1991;83:154–158.

3. Kelly R, Mehrhoff M. *Radon-222 in the Source and Finished Water of Selected Public Water Supplies in Iowa.* Iowa City, Iowa: University of Iowa Hygienic Laboratory; 1993. Research Report 93-1.

4. *Radon in Water Sampling Program.* Montgomery, Ala: US Environmental Protection Agency; 1978. EPA/EERF-Manual-78-1.

5. Hahn P, Pia S. *Determination of Radon in Drinking Water by Liquid Scintillation Counting.* Las Vegas, Nev: Environmental Protection Agency; 1991.

6. Field RW, Kross BC. Iowa survey of waterborne ^{222}Rn concentrations in private wells. In: Proceedings of the International Radon Conference, September 1993, Denver, Colo.

7. Valentine RL, Stearns S, Kurt A. Radon and radium from distribution system and filter media deposits. In: Proceedings of the American Water Works Association Water Technology Conference, November 1992, Toronto, Ontario, Canada.

8. Stearns SW. *Radon Formation in Drinking Water Distribution Systems from Radium Containing Deposits.* Iowa City, Iowa: University of Iowa; 1993. Thesis.

9. Valentine RL, Stearns SW. Radon release from water distribution system deposits. *ES&T.* 1994;28:534–537.

10. Levinson AA. *Introduction to Exploration Geochemistry.* Wilmette, Ill: Applied Publishing Ltd; 1980:652–654.

11. Brinck WL, Schliekelman RJ, Bennent DL, Bell C, Markwood IM. Radium removal efficiencies in water treatment processes. *J Am Water Works Assoc.* 1978;70:31–43.

12. Reid GW, Lassovszky P, Hathaway S. Treatment, waste management and cost for removal of radioactivity from drinking water. *Health Phys.* 1985;48:671–694.

13. Valentine RL, Mulholland TS, Splinter RC. Radium removal using sorption to filter sand. *J Am Water Works Assoc.* 1987;79:170–176.

14. Valentine RL, Spangler KM, Meyer J. Removing radium by adding preformed hydrous manganese oxides. *J Am Water Works Assoc.* 1990;82:66–71.

Water Chlorination and Lipo- and Apolipoproteins: The Relationship in Elderly White Women of Western Pennsylvania

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A B S T R A C T

The relationship between consumption of chlorinated drinking water in the home water supply and serum lipids was examined in 2070 elderly White women. Private springs, cisterns, and wells were considered nonchlorinated and public water sources, chlorinated. Mean serum lipids and lipoproteins were similar in the chlorinated and nonchlorinated groups. Stratification by years of exposure revealed little difference in lipid concentrations. Lifestyle factors—for example, smoking and alcohol consumption—differed by years of exposure. Hence, previous reports of an association between chlorinated drinking water and serum cholesterol levels may reflect inadequate control of other factors differentially distributed across chlorinated exposure groups. (*Am J Public Health.* 1995;85:570–573)

Introduction

Chlorination has been used as a water disinfectant in the United States since 1908,[1] and approximately 200 million Americans are currently exposed to chlorinated drinking water.[2] Early animal studies suggested that exposure to chlorinated drinking water may increase serum lipids,[3–6] perhaps via alterations in thyroid function.[6] However, a more recent study did not support these findings,[7] and clinical studies in which individuals were given water with various concentrations of chlorine showed no effect on serum cholesterol.[8–10] A recent cross-sectional study of 866 women and 654 men in Wisconsin towns did show significantly higher serum cholesterol in those exposed to chlorinated drinking water than in those not exposed, but this association was confined to women aged 50 to 59.[11] Nevertheless, given the widespread exposure to chlorinated drinking water, an effect of chlorine on cholesterol levels is potentially a great public health concern.[12–15] The present study was conducted to replicate the findings from Wisconsin in a second human population.

Methods

The study sample included 2070 non-Black women, aged 65 to 93 years, living in the community; all were participants in the Study of Osteoporotic Fractures.[16] Total cholesterol was measured in all 2070 women using the portable Kodak DT-60 machine. In a subset of 821 women, full lipid profiles were measured in the University of Pittsburgh's Heinz Nutrition Laboratory, a Centers for Disease Control lipid-certified laboratory. Cholesterol and triglycerides were measured enzymatically.[17,18] Low-density lipoprotein (LDL) cholesterol was calculated with the Friedewald equation.[19] The total high-density lipoprotein (HDL) cholesterol was precipitated with heparin and

manganese chloride.[20] The HDL-2 subfraction cholesterol was then precipitated with dextran sulfate and HDL-3 subfraction was measured in the supernatant.[21] HDL-2 was calculated as the difference between the total HDL and HDL-3. Apolipoproteins Apo AI and Apo B100 were determined using the Boehringer Mannheim Turbidimetric Method with modifications for the Abbott VP Spectrophotometer.

Alcohol consumption, smoking history, physical activity, and use of estrogen were assessed in the baseline questionnaire. The variable for alcohol consumption used in this analysis was the number of ounces of ethanol per week, adjusted for atypical amounts. The average number of years smoking and the number of packs smoked per year were used to estimate pack years. Current leisure time physical activity was assessed using a modified Paffenbarger questionnaire and was expressed in kilocalories per week.[22] Subjects were asked the frequency with which they leave the neighborhood and get out of the house in good weather.

A residential history questionnaire was used to obtain information on home water source (public, private well, cistern, spring) at each residence from 1950 to 1990. Water companies were contacted to verify service area. The zip codes of each residence was matched with that of a particular water company. If zip codes overlapped within a water service area, street maps and additional verification with water companies was carried out. All public water sources were chlorinated; all private well, cistern, or spring supplies were considered nonchlorinated.[23–26] Women reporting a mixture of public and private water sources were considered exposed to chlorinated drinking water at their home.

Skewed variables were log transformed for statistical analyses. Untransformed data are presented in the tables. Serum lipids and other risk factors among women currently exposed to chlorine were compared with those factors among women not currently exposed to chlorine using Student's *t* test. Subjects were stratified by years of exposure to chlorinated drinking water (0, 1 to 15, 16 to 39, ≥ 40), and their serum lipids and other risk factors were compared across these strata using analysis of variance and covariance.

Results

Two hundred one women (9.7%) reported current use of nonchlorinated

TABLE 1—Demographic Factors among Sample, by Current Chlorine Exposure

	Chlorinated (n = 1869)[a]		Nonchlorinated (n = 201)[a]		
	Mean	SD	Mean	SD	P
Age, y	71.1	4.9	70.1	4.7	.01
Body mass index, wt/ht²	27.6	4.9	28.1	5.1	.18
Smoking, pack years	9.7	20.0	7.4	18.9	.02[b]
Alcohol consumption, ethanol oz/wk	0.4	1.3	0.3	1.1	.65[b]
Physical activity, kcal/wk	1299	1382	1692	2003	.15[b]

[a]Totals may vary because of missing numbers.
[b]Probability was evaluated on log-transformed data: Log (variable +1).

TABLE 2—Lifestyle Factors among Sample, by Current Chlorine Exposure

	Chlorinated (n = 1869),[a] %	Nonchlorinated (n = 201),[a] %	P
Education (> high school)	17.5	23.3	.04
Estrogen (ever use)	23.3	23.3	.99
Leave neighborhood at least once a day	36.0	33.4	.54
Get out of the house at least once a day	82.3	88.6	.18
Bottled water (ever use)	6.6	5.2	.95

[a]Totals may vary because of missing numbers.

TABLE 3—Lipids, Lipoproteins, and Apolipoproteins (mg/dL) among Sample, by Current Chloride Exposure

	Chlorinated (n = 1869)[a]			Nonchlorinated (n = 201)[a]			
	n	Mean	SD	n	Mean	SD	P
Total cholesterol	1752	247.0	41.3	192	246.4	41.9	.83
HDL cholesterol	818	55.1	12.8	96	55.1	13.0	.99
LDL cholesterol	797	147.0	36.8	96	149.5	36.2	.54
Triglycerides	815	156.9	88.4	96	144.3	74.1	.16[b]
Apo A1	721	145.6	21.4	86	147.7	23.4	.40
Apo B	722	91.8	21.8	86	94.8	24.5	.22

Note. HDL = high-density lipoprotein; LDL = low-density lipoprotein.
[a]Totals may vary because of missing numbers.
[b]Probability was evaluated on log-transformed data: Log (variable +1).

springs, cisterns, or wells as their primary source of water in the home; 35 women (1.7%) reported mixed sources of water (public and private), and 1834 women (88.6%) reported public water in the home (Table 1). The average years of exposure to their current water source was similar for women with private and public water sources (mean = 31 ± 11 years, private; mean = 30 ± 13 years, public). Women currently exposed to chlorinated drinking water were older and

reported a greater number of pack years smoking and greater alcohol consumption (Table 1) but they had slightly lower education levels (Table 2). There was no difference in use of estrogen or bottled water or in the frequency with which they got out of the house. Mean serum lipids were similar in women currently exposed to chlorinated drinking water and those not exposed (Table 3).

Women with greater duration of exposure to chlorinated drinking water in

TABLE 4—Demographic Factors among Sample, by Years of Exposure to Chlorinated Drinking Water at Home

	0 Years (n = 127)[a]		1–15 Years (n = 212)[a]		16–39 Years (n = 200)[a]		≥ 40 Years (n = 1531)[a]		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P
Age, y	70.8	5.0	70.1	4.3	70.4	5.0	71.2	5.0	0.54
Body mass index, wt/ht^2	27.9	5.0	28.2	5.0	27.9	5.2	27.5	4.9	0.36
Smoking, pack years	6.9	19.4	6.6	16.0	10.0	20.4	9.9	20.3	0.01[b]
Alcohol consumption, ethanol oz/wk	0.3	1.3	0.4	1.6	0.5	1.7	0.4	1.2	0.04[b]
Physical activity, kcal/wk	1646	2214	1461	1519	1493	1659	1275	1334	0.67[b]

[a]Totals may vary because of missing numbers.
[b]Probability evaluated on log transformed data: Log (variable + 1).

TABLE 5—Lifestyle Factors among Sample, by Years of Exposure to Chlorinated Drinking Water at Home

	0 Years (n = 127),[a] %	1–15 Years (n = 212),[a] %	16–39 Years (n = 200),[a] %	≥ 40 Years (n = 1531),[a] %	P
Education (> high school)	21.3	25.0	16.0	17.7	0.06
Estrogen use (ever use)	22.3	18.7	25.4	24.2	0.32
Least neighborhood at least once per day	28.3	34.0	36.5	36.5	0.23
Get out of the house at least once per day	89.0	86.0	86.6	83.0	0.12
Bottled water (ever use)	5.5	6.2	7.0	6.7	0.94

[a]Totals may vary because of missing numbers.

the home had greater levels of smoking (more pack years) and alcohol consumption (more ounces of ethanol per week) (Table 4). A lower percentage of women with 40 or more years of chlorine exposure reported greater than a high school education (Table 5). There was no difference in estrogen use, mobility, and use of bottled water across chlorinated exposure groups (Table 5).

There was some suggestion that women who reported no exposure to chlorinated drinking water at home had lower cholesterol, but the results were not statistically significant (Table 6). No relationship was observed for LDL cholesterol or Apo-B, both of which are known to correlate with total cholesterol. There was also no evidence that increasing duration of exposure to chlorinated drinking water influenced HDL cholesterol, Apo AI, or triglycerides.

Discussion

We examined the relationship between exposure to chlorinated drinking water and lipids in a large population-based group of elderly women. Serum cholesterol values were similar in women currently exposed to chlorinated drinking water at home and in those currently not exposed. There was no evidence to suggest that increasing duration of exposure to residential chlorinated drinking water influenced apo- or lipoprotein levels. Women exposed to chlorine in the home tended to smoke and drink more than women unexposed to chlorine, suggesting that previous reports of an association may reflect inadequate control of other lifestyle factors differentially distributed across exposure groups.

One of the limitations of this study is the possible misclassification of those

exposed to chlorine in the nonchlorinated group, which could have resulted because of exposure to chlorinated drinking water outside the home, exposure to other sources of chlorine, or use of bottled water among those in the chlorinated group. This would decrease the possibility of detecting a difference between groups if there were one. However, there was no evidence that the frequency with which the women reported leaving their neighborhood or going out differed across the chlorinated exposure groups. Few women reported drinking bottled water, and this did not differ across the chlorinated exposure groups. The study had sufficient power to detect a difference in total cholesterol of 10 mg/dL, α = 0.05, one-tail, 1-β = 0.80, which corresponds to one fourth of one standard deviation in total cholesterol.

In summary, this study provides little support for the hypothesis that exposure to chlorinated drinking water is associated with higher serum lipid levels in older women. □

References

1. Johnson GA. Hypochlorite treatment of public water supplies: its adaptability and limitations. *J Am Public Health Assoc.* 1911;1:562–574.
2. *Survey of Operating and Financial Characteristics of Community Water Systems.* Washington, DC: US Environmental Protection Agency, Office of Water Supply; 1977. EPA publication 570/9-77-003.
3. Bercz JP, Jones L, Mills T, Stober J, Cicmanec J, Condie L. Association between chlorinated drinking water and decreased serum HDLc in two monkey species during dietary atherogenic stress. In: Jolley RL, Condie LW, Johnson DJ, et al., eds. *Water Chlorination: Chemistry, Environmental Impact and Health Effects.* Chelsea, Mich: Lewis Publishers; 1990;6: 293–299.
4. Revis NW, Osborne TR, Holdsworth G, McCauley P. Effect of chlorinated drinking water on myocardial structure and functions in pigeons and rabbits. In: Jolley RL, Condie LW, Johnson DJ, et al., eds. *Water Chlorination: Chemistry, Environmental Impact and Health Effects.* Chelsea, Mich: Lewis Publishers; 1985;5:365–371.
5. Revis NW, McCauley P, Bull R, Holdsworth G. Relationship of drinking water disinfectants to plasma cholesterol and thyroid hormone levels in experimental studies. *Proc Natl Acad Sci.* 1986;83:1485–1489.
6. Revis NW, McCauley P, Holdsworth G. Relationship of dietary iodine and drinking water disinfectants to thyroid function in experimental animals. *Environ Health Perspect.* 1986;69:243–248.
7. Penn A, Lu MX, Parkes JL. Ingestion of chlorinated water has no effect upon indicators of cardiovascular disease in pigeons. *Toxicology.* 1990;63:301–313.

TABLE 6—Lipids, Lipoproteins, and Apolipoproteins (mg/dL) among Sample, by Years of Exposure to Chlorinated Drinking Water at Home

	0 Years (n = 127)[a]			1–15 Years (n = 212)[a]			16–39 Years (n = 200)[a]			≥ 40 Years (n = 1531)[a]			
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	P
Total cholesterol	120	240.8	0.7	206	248.7	40.5	190	251.9	44.9	1428	246.6	41.3	0.10
HDL cholesterol	59	54.8	11.5	97	55.7	14.5	83	56.7	12.9	675	54.8	12.6	0.81
LDL cholesterol	59	146.7	31.8	94	144.1	35.8	82	150.3	36.9	658	147.4	37.3	0.51
Triglycerides	59	138.5	68.9	96	162.7	148.7	83	148.1	80.7	673	156.9	86.9	0.33[b]
Apo A1	53	148.3	24.4	86	146.8	21.4	74	147.9	18.5	594	145.2	21.8	0.46
Apo B	53	94.3	24.0	87	4.4	24.5	74	91.4	22.6	594	91.7	21.5	0.26

Note. HDL = high density lipoprotein; LDL = low density lipoprotein.
[a]Totals may vary because of missing numbers.
[b]Probability evaluated on log transformed data: Log (variable +1).

8. Lubbers JR, Chauan S, Bianchine JR. Controlled clinical evaluations of chlorine dioxide, chlorite, and chlorate in man. *Environ Health Perspect.* 1982;46:57–62.

9. Wones RG, Glueck CJ. Effects of chlorinated drinking water on human lipid metabolism. *Environ Health Perspect.* 1986; 69:255–258.

10. Wones RG, Mieczkowski L, Frohman LA. Effects of drinking water chlorine on human lipid and thyroid metabolism. In: Jolley RL, Condie LW, Johnson DJ, et al., eds. *Water Chlorination: Chemistry, Environmental Impact and Health Effects.* Chelsea, Mich: Lewis Publishers; 1990;6:301–308.

11. Zeighami EA, Watson AP, Craun GF. Chlorination, water hardness and serum cholesterol in forty-six Wisconsin communities. *Int J Epidemiol.* 1990;19:49–58.

12. Wallace RB, Anderson RA. Blood lipids, lipid-related measures, and the risk of atherosclerotic cardiovascular disease. *Epidemiol Rev.* 1987;9:95–119.

13. Abbott RD, Wilson PW, Kannel WB, Castelli WP. High density lipoprotein cholesterol, total cholesterol screening, and myocardial infarction: the Framingham Study. *Arteriosclerosis.* 1988;8:207–211.

14. Gordon DJ, Probstfield JL, Garrison RJ, et al. High-density lipoprotein cholesterol and cardiovascular disease: four prospective American studies. *Circulation.* 1989;79: 8–15.

15. Castelli MD, Doyle JD, Gordon T, et al. HDL cholesterol and other lipids in coronary heart disease: the Cooperative Lipoprotein Phenotyping Study. *Circulation.* 1977;55:767–772.

16. Cummings SR, Black DM, Nevitt MC, et al. Appendicular bone density and age predict hip fracture in women. *JAMA.* 1990;263:665–668.

17. Allain CC, Poon LS, Chan CS, et al. Enzymatic determination of total serum cholesterol. *Clin Chem.* 1974;20:470–475.

18. Bucolo Q, David H. Quantitative determination of serum triglycerides by the use of enzymes. *Clin Chem.* 1973;19:476–482.

19. Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clin Chem.* 1972;18:499–502.

20. Warnick GR, Albers JJ. A comprehensive evaluation of the heparin-manganese precipitation procedure for estimating high density lipoprotein cholesterol. *J Lipid Res.* 1978;19:65–76.

21. Gidez LI, Miller GJ, Burstein M, et al. Separation and quantitation of subclasses of human plasma high density lipoproteins by a simple precipitation procedure. *J Lipid Res.* 1982;23:1206–1223.

22. Paffenbarger RS, Wing AL, Hyde RT. Physical activity as an index of heart attack risk in college alumni. *Am J Epidemiol.* 1978;108:161–175.

23. Newport TG. *Summary Ground Water Resources of Washington County, Pennsylvania.* Harrisburg, Pa: Pennsylvania Geological Survey, Fourth Series; 1973. Water Resource Report 38.

24. Newport TG. *Summary Groundwater Resources of Westmoreland County, Pennsylvania.* Harrisburg, Pa: Pennsylvania Geological Survey, Fourth Series; 1973. Water Resource Report 35.

25. Gallaher JT. *Summary Groundwater Resources of Allegheny County, Pennsylvania.* Harrisburg, Pa: Pennsylvania Geological Survey, Fourth Series, 1973. Water Resource Report 35.

26. McElroy TA. *Groundwater Resources of Fayette County, Pennsylvania.* Harrisburg, Pa: Topographic and Geologic Survey, 1988. Water Resource Report 60.